10/781222

Express Mail No.: EV439629481US
Date of Deposit: February 18, 2004

FIELD OF THE INVENTION

The invention relates generally to wireless networks, and more particularly to wireless network configuration and power level adjustment for network performance optimization.

BACKGROUND OF THE INVENTION

The proliferation of laptop and hand-held portable computers has produced a concomitant need for robust, reliable, and high performance wireless networks to maximize the mobility advantages of these devices and increase the ease of construction and management of these wireless networks. Current wireless networks, such as IEEE 802.11b, 802.11a, 802.11g, (etc) networks, are subject to certain limitations that can limit a mobile user's network performance and reliability. For instance, only a very limited number of radio channels are available. In the current state of the art, wireless access points cannot effectively share the same channel in the same area because of radio and control protocol interference. So, bandwidth over a given area is limited by the number of non-overlapping channels available. Also, current wireless networks require manual site engineering to control the placement of access points and channel distribution between access points, raising the cost and complexity of the wireless network installation process. Furthermore, user roaming between wireless access points is

inconsistent. Once associated with an access point, a user will tend to remain associated with that access point even if another access point is capable of providing higher performance for the user. It would be desirable to provide wireless networking solutions which overcome the above described inadequacies and shortcomings of current wireless networks.

SUMMARY OF THE INVENTION

In accordance with the principles of the invention, various apparatus, methods, and computer program products are provided to improve the performance and ease of management of wireless communications environments. For example, a mechanism is provided to enable access points (APs) to perform automatic channel selection. A wireless network can therefore include multiple APs, each of which will automatically choose a channel such that channel usage is optimized. Furthermore, APs can perform automatic power adjustment so that multiple APs can operate on the same channel while minimizing interference with each other. Further aspects of the invention are used to cause load balancing of stations across APs so that user bandwidth is optimized. Novel movement detection schemes provide seamless roaming of stations between APs. These and further aspects of the invention enable the provision of automatically configurable, high performance wireless communications environments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a wireless communications environment in which wireless users interact with other networked devices via an access point (AP).

Figure 2 shows a wireless network in which wireless user devices, or stations (STAs), access the wireless network via an access point and share the available network bandwidth.

Figure 3 shows a wireless network wherein the stations access the network via two separate access points.

Figure 4 is a flow diagram representing how an AP builds a channel map for use in an automatic channel selection scheme.

Figure 5 is a flow diagram representing an automatic channel selection method.

Figure 6 is a representation of a table kept by APs for use in an alternate channel selection scheme.

Figure 7 is a flow diagram representing an alternate automatic channel selection scheme.

Figures 8A - 8B are

Fi~~gure 8 is~~ a flow diagram representing a preferred embodiment of an automatic channel selection scheme.

Figure 9 is a representation of a Scan Table kept by APs for use in the automatic channel selection scheme of Figure 8.

Figure 10 is a representation of a Channel Map kept by APs for use in the automatic channel selection scheme of Figure 8.

Figure 11 is a representation of a Triplet Channel Map kept by APs for use in the automatic channel selection scheme of Figure 8.

Figure 12 is a representation of a Claim APs table kept by APs for use in the automatic channel selection scheme of Figure 8.Figure 13 is a flow diagram showing how an AP builds an AP KnownAPs table.

Figure 14 is an example of an AP KnownAPs table maintained by an AP, and used for power adjustment.

Figure 15 is a flow diagram representing the process by which an AP builds an AP AssociatedSTA table, for use in load balancing.

Figure 16 is an example of an AP AssociatedSTA table.

Figure 17 is a block diagram representing a general mechanism by which an AP adjusts its transmit power backoff.

Figure 18 is a block diagram representing a preferred embodiment of the transmit power backoff mechanism of Figure 13.

Figure 19 is a table showing expected standard errors related to number of power level samples.

Figure 20 is a flow diagram representing the process by which an AP adjusts its transmit power backoff during STA movement.

Figure 21 is a flow diagram representing an AP auction process, used for load balancing of STAs across APs.

Figure 22 is a flow diagram representing the AP's handling of bids during the auction.

Figure 23 is a flow diagram representing the STA initialization process.

Figure 24 is a flow diagram representing a general mechanism by which a STA in a wireless communications environment canvasses channels.

Figure 25 is a flow diagram representing the preferred embodiment of Figure 20 as implemented in an 802.11 wireless networking environment.

Figure 26 is an example of a STA Known APs table, used by STAs for power adjustment and load balancing.

Figure 27 is a flow diagram representing the process by which the STA Known APs table is built by a STA.

Figure 28 is a flow diagram representing the STA power adjustment process.

Figure 29 is a flow diagram representing the STA Bidding process.

Figure 30 is a flow diagram representing the process by which a STA calculates corrected distances for use in determining whether to bid for an AP.

Figure 31 is an example of a distance_to_rate table for use in an 802.11 wireless networking environment.

Figure 32 is an example of a rate_to_load table for use in an 802.11 wireless networking environment.

Figure 33 is a flow diagram representing the STA Bidding process in more detail.

Figure 34 is a flow diagram representing the process by which a STA detects its own movement.

Figure 35 is a block diagram showing the software architectures of APs and STAs.

Figure 36 is a more detailed block diagram of the software architecture of an AP implementing the invention in an 802.11 wireless networking environment.

Figure 37 is a more detailed block diagram of the software architecture of a STA implementing the invention in an 802.11 wireless networking environment.

Figure 38 represents the encoding of a DRCP (Dynamic Radio Control Protocol) message in an 802.11 beacon frame.

Figure 39 represents the encoding of a DRCP message in an 802.11 data frame.

Figure 40 is a table summarizing the DRCP messages used in the various aspects of the invention.

Figure 41 is a table describing the various fields used in DRCP messages.

Figure 42 is a diagram of the message format of a DRCP Preclaim message.

Figure 43 is a diagram of the message format of a DRCP Claim message.

Figure 44 is a diagram of the message format of a DRCP Announce message.

Figure 45 is a diagram of the message format of a DRCP Bid message.

Figure 46 is a diagram of the message format of a DRCP Accept message.

Figure 47 is a diagram of the message format of a DRCP Registration Request message.

Figure 48 is a diagram of the message format of a DRCP Registration Acknowledge message.

Figure 49 is a graph showing discrete measurements of received power over time from the perspective of a wireless network user.

Figure 50 is a graph showing discrete measurements of received power over time from the perspective of a wireless network user, and showing the estimated average received power for the user within a 99% confidence interval.

Figure 51 is a graph similar to Figure 3 showing two different estimated average received power measurements for small sample sizes and their 99% confidence intervals.

Figure 52 is a graph showing two different estimated average received power measurements and their 99% confidence intervals, one for a large sample size and one for a small sample size.

Figure 53 is a graph showing a long term average measurement and a short term average measurement with 99% confidence interval, the comparison showing that it can be determined that a user has moved.

Figure 54 is a table showing the number of samples that need to be taken in order to cause the long term average confidence interval range to converge toward zero.

Figure 55 is a flow diagram of the general operation of the method of the invention.

Figure 56 is a block diagram of an embodiment of a wireless network in which the invention is deployed, wherein an AP ascertains that a user has moved.

Figure 57 is a block diagram of an alternate embodiment of the invention, wherein a user ascertains that the user has moved.

Figure 58 is a block diagram of one embodiment of the invention employing ring buffers.

Figure 59 is a block diagram of an alternate embodiment of the invention employing batched means.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

In accordance with the present invention, a fully automatic control system is provided for wireless communications environments. Referring to Figure 1, a typical wireless communications environment 10 includes access devices 12 (one shown) that interface between a wired communications medium 14 and wireless devices 16 to provide network access to the wireless devices 16. Wireless devices 16 can thus communicate with wired devices 18 and with each other via the access device 12. These access devices 12 are referred to by various names depending upon the wireless architecture employed,

and are herein referred to as "access points" or "APs". The wireless devices 16 also have various architecture dependent names and are herein referred to as "stations" or STAs. A wireless communications capable device may be an AP, or a STA, or both.

Various types of wireless communications environments 10 exist. Wireless communications environments include for example wireless data networks and wireless I/O channels. An example of a wireless data network is described in "IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications—Amendment 1: High-speed Physical Layer in the 5 GHz band", incorporated herein by reference(hereinafter "802.11"). Furthermore, various different 802.11 "modes" are defined. For example, in IEEE 802.11 compatible wireless networks, wireless devices may be arranged in an "infrastructure mode", whereby the network is configured such that STAs 16 communicate with other network devices via an AP 12, as shown in Figure 1. 802.11 compatible devices may also be arranged in "ad-hoc" mode, whereby all the STAs 16 are within transmission range and can communicate directly with each other. Furthermore, wireless "mesh" technologies exist, whereby each wireless device acts as both an AP and a STA. Wireless I/O channels can be used to provide I/O communications, for example, between servers and storage devices via the "Bluetooth" Standard, or between home entertainment audio and video components , or between wireless telephone handsets and base stations. The various aspects of the

invention apply to generally to wireless networking architectures, including those used in wide area networks, metropolitan area networks, enterprise networks, and home networks, and wireless I/O channel architectures, as they exist now and as they are developed.

According to aspects of the invention, an arbitrary number of wireless access points (APs) can be placed in arbitrary positions, and all APs and STAs will automatically configure themselves for optimal channel usage, power levels, and STA/AP associations. So, in a wireless networking environment, channel usage is optimized while interference between APs is minimized. Wireless devices such as wireless enabled laptops or hand-held computing devices or Internet protocol telephones, are transparently and seamlessly distributed between APs such that network performance is optimized from the perspective of the user of the wireless device. And, in a wireless I/O channel environment that might be employed for example in a home, audio, video, and other appliances may be moved without performance degradation, and channel usage for each appliance may be optimized so that the appliances do not interfere with each other.

In order to expedite the understanding of the invention, certain examples will be described as they apply to the relatively well known 802.11 wireless LAN architecture, with the understanding that the principles of the invention apply more generally to any wireless communications environment. A preferred implementation of the inventive principles will then be described as embodied in an 802.11 wireless network

The following aspects of the invention contribute to its advantages, and each will be described in detail below.

1. AP Initialization: In many wireless communications environments, multiple frequencies ("channels") are available for use by APs. For example, in accordance with 802.11b and 802.11g, 3 non-overlapping channels are available. In accordance with IEEE 802.11a, 13 non-overlapping channels are available. In an environment where multiple APs are employed, it will be seen that it is advantageous for the APs to use different channels to optimize performance and minimize interference. In accordance with the invention, APs perform automatic channel selection. Where multiple APs are distributed in a given area, the APs execute a distributed protocol to pick channels for each AP. APs close to each other use non-overlapping channels.

1. AP Optimization:

    a. Power Adjustment: When the number of APs in a wireless communications environment exceeds the number of non-overlapping channels, APs and STAs adjust their power such that APs and STAs on the same channel can co-exist in an area without interference. For APs using the same channel, APs continually re-adjust their power levels based on environmental factors such as signal strength changes due to movement of doors, people, background noise floor, and the like, so that the users' optimal bandwidth is maintained without undue interference.

a. Auction: APs keep track of various parameters for STAs that are associated with them, and STAs will roam between APs for load balancing purposes, which can help to maximize performance over a group of STAs.

1. STA initialization: STAs associate with an initial AP. Invention enabled STAs turn on functions that allow them to receive messages from invention enabled APs.

1. STA optimization:

   a. Channel Canvassing: In order to further optimize performance, STAs periodically canvass the other channels in the band in which the STA is operating to see if a "better" AP is present. To ascertain whether another AP is "better", various parameters are considered, such as signal strength and load factors, to be further described.

   a. Bidding: If a better AP is found, a STA enters a bidding process to try to cause the STA to roam to the better AP. Load balancing is thereby achieved. In addition, the bidding process accommodates STA movement by causing the STA to associate to a better AP after it has moved closer to the better AP.

   a. Power Adjustment: STAs perform power adjustment such that they can maintain throughput to and from their currently associated AP while minimizing the interference with nearby wireless devices that may be using the same channel.

a. Movement Detection: STAs perform movement detection so that the bidding process can be turned off while a STA is moving, and then turned back on when the STA has stopped moving. When turned back on, a "better" AP may turn up and thus the STA will bid for it.

1. Software Architecture

   a. The above functionality is advantageously implemented in APs and STAs in a modular manner for ease of transfer between platforms.

   a. The above functionality is described in detail as it is implemented in a preferred 802.11 network embodiment.

1. Movement Detection statistical analysis: A novel scheme for highly accurate and computationally efficient detection of a change in an attribute subject to high noise variation is described, and applied to detection of the movement of wireless STAs.

Since exemplary examples will refer to the 802.11 networking environment, the following information provides relevant context, while understandably not limiting the invention to 802.11 environments.

In an 802.11 network, APs periodically send frames called "Beacons". STAs listen for Beacons. When an unassociated STA (i.e. a STA that is not yet able to communicate on the wireless network) hears Beacons at what it deems to be a reasonable power level, it can attempt to authenticate with the AP sending the Beacons, and then

associate with that AP. Once authenticated and associated, the STA is able to send data frames to other STAs on the wireless network via the AP.

More particularly, APs and STAs send and respond to three different types of frames, known as Class 1 Frames, Class 2 Frames, and Class 3 Frames. Class 1 Frames include control frames and management frames, and can be sent regardless of whether a STA is authenticated and associated with an AP. A Beacon is a type of Class 1 frame. Class 2 Frames are sent only once a STA is authenticated, and include for example association request / response messages. Class 3 Frames can be sent only if associated, and include data frames.

In order to maximize user bandwidth and throughput, the invention automatically optimizes the operation of multiple APs for a given wireless communications environment. In accordance with the exemplary IEEE 802.11a networking standard, 13 non-overlapping frequencies are available for use by the APs. Each AP is capable of transmitting and receiving data at a maximum rate of 54 Mbps. The actual rate at which data is transmitted and received between an AP and a STA depends upon many factors, including the distance between the AP and the STA, the structures located between the AP and the STA, and the environmental interference occurring on the particular frequency. One skilled in the art will realize that the invention is not limited by the maximum data rates of current wireless technology, nor is it limited by currently understood radio frequency attenuation factors. The principles of the invention will continue to be applicable as wireless technology evolves.